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DRY BEAN AGRONOMY: OPTIMIZING THE DRYLAND PRODUCTION SYSTEM

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Dry Bean Agronomy: Optimizing the dryland production system

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1 Abstract

The objective of this study is to develop a dryland agronomic system for growing dry bean. CDC Expresso requires higher plant populations to reach a yield maximum that CDC Camino. CDC Camino and CDC Expresso should be seeded to a target density of 25 and 50 plants m^{-2} to maximize profits. It has been determined that nitrogen fertilizer can increase the yield of dry beans Adding 65lbs/ac of nitrogen fertilizer increased the yield of average yield of dry beans by 25% in 2000 and a 42% increase in 1999. The difference in response between the years were due to two sites that had low yield potential in 2000. Overall rhizobium inoculation did not have a significant effect on dry bean yield. However, in 2000 when there was better control for cross contamination, inoculation did result in higher yields at 0 and 25 kg N ha^{-1}. Both no-till and cultivated tillage systems seem suitable for bean production so long as the amount of crop residue is not excessive.

2 Executive Summary

The global objective of this study is to develop a dryland agronomic system for growing dry beans in the thin black soil zone of Saskatchewan. There are two components to this research project. The first is traditional plot-based agronomic research in order to answer specific agronomic questions. The second component consists of working with producers to develop the dry bean production system. These two approaches have a synergy in that the information on agronomic practices is channelled directly to the producers so that

adaptation is very quick. In addition by being involved in "real" production, the researchers and producers can quickly identify gaps in the agronomic package which can be addressed the next research year with experiments. This approach expedites the process of developing a profitable production system for dryland dry bean production. In 2000 we worked with the North Central Dry Bean Producers located at Rosthern, Saskatchewan. Approximately ten producers grew dry beans in the Rosthern area in 2000

The effect of seeding system on dry bean yield, height and maturity.

Direct-seeding of dry bean (*Phaseolus vulgaris*) has not been widely adopted in dryland production areas of Saskatchewan. A field study was established to evaluate the effect of pre-seeding residue management on dry bean emergence, yield, pod clearance, and maturity. Cultivated (cultivated, harrowed), mowed (stubble cut and spread) and stubble treatments were applied to plots were prior to seeding in the spring. Two dry bean cultivars were seeded into each residue management plot. Soil temperatures and moisture levels were measured for residue management treatments. During the first year of the study, cultivated treatments had lower plant densities than the other two treatments but yields were equal. During the second year, stubble treatment yields were similar to cultivated treatment yields, but mowed treatment yield was reduced. The percentage of immature and poor quality seed was higher in the mowed treatments than in the cultivated or stubble treatments. Initiation of flowering and pod maturation was advanced in the cultivated treatment compared with the mowed treatment at the Saskatoon location. Residue management had little effect on bean pod clearance and internode length. The mowed treatment was the least preferable residue management treatment probably because this treatment had the highest level of surface residue. The standing stubble treatment was generally similar to the cultivated treatment in terms of maturity, yield and yield quality. Results of this study indicate that no-tillage and spring-cultivated bean production are equally possible when surface residue conditions are not excessive.

The effect of nitrogen fertilizer on yield and nitrogen fixation in dry bean

This study was conducted at three locations including Saskatoon, Rosthern and Melfort. Nitrogen fertilizer was banded at 0, 25, 50, 75 kg ha^{-1} in inoculated and uninoculated plots of CDC Expresso and CDC Camino dry beans. In 2000 a 100 kg ha^{-1} treatment was added and the locations of Redvers and Canora were included.

Nitrogen fertilizer increased bean yield in both 1999 and 2000. The greatest yield increases came under the best growing conditions. In general when the beans were growing well they responded to nitrogen fertilizer.

Due to the possibility of between plot contamination in the 1999 experiment only the 2000 results for inoculation will be discussed. Rhizobium inoculation resulted in a yield increase at three of the four locations in 2000. The average yield increase was 8.5%, with Expresso having a greater response to rhizobium than Camino at one location. In 2000 the inoculation effect was greater when 0 or 25 kg ha^{-1} fertilizer nitrogen was added.

The effect of harvest technology on harvest efficiency

Rake up crop lifters were obtained and installed on a Winter Stieger plot combine. The Rake up lifters could not be installed in the recommended manner on the small plot combine resulting in the angle being steeper than intended. Under these conditions the rake up lifters reduced the harvested bean yield by 24%. This was because of a 39% increase in seed loss at harvest. These results are the opposite of what was expected and may be attributed to the modified installation on the plot combine. As we did not have access to other equipment this experiment was not repeated. The Un-Reel has not finished prototype tests so it was unavailable for testing. These results indicate that producers should monitor cutter bar yield losses whenever modifications are performed.

The effect of seeding rate on the yield of two dry bean cultivars

The recommendations for seeding density for dry beans can depend on the growth habit of the plant, the yield density relationship, percent emergence, seed cost and environment. The objective of this study was to determine the yield density relationships in two determinate bush type growth habit cultivars of dry bean and the optimum plant population under solid seeded production system in Saskatchewan. CDC Camino, a late season pinto bean and CDC Expresso, a medium season length black bean were the cultivars evaluated. CDC Camino and CDC Expresso were seeded 20,40, 60, 80 and 100 seeds m^{-2}. In most sites the yield density relationship of the dry beans cultivars was asymptotic and an optimum plant density for biological yield could not be determined. CDC Camino generally required a lower plant population to reach a given yield than CDC Expresso. Increasing plant population had little effect on thousand seed weight in both cultivars. Seeding rate always had a significant effect on seeds produced per m^2. CDC Expresso was required to be at higher plant densities than CDC Camino to maximize economic returns. This reflects the differences between cultivars in the yield-density relationships and seed cost, as CDC Camino has a higher 1000 seed weight than CDC Expresso. Saskatchewan bean growers wishing to maximize profit should target plant populations for CDC Expresso and CDC Camino of approximately 50 and 25 plants m^{-2} respectively.

3 Technical Report

3.1 Background

The overall objective of this research is to refine the narrow row agronomic package for dry bean production in the thin black soil zone of Saskatchewan. The CDC has developed dry bean varieties adapted for dry land production. These adaptations include upright growth, short growing season and improved pod clearance. What is now needed is for the agronomic package to be refined to allow producers to profitably grow this crop.

3.2 Technical Report

This project was developed as a series of specific sub-projects, each with specific goals. Progress is described below for each sub-project

3.2.1 The effect of seeding system on dry bean yield, height and maturity.

It should be noted that the varieties chosen for this study were changed as to have two black bean varieties differing in growth habit. CDC Expresso is a type I (Bush type, determinant) bean, whilst CDC Nighthawk is a type II (bush type, indeterminate).

Direct seeding and other types of residue management may influence bean productivity in several ways. Direct-seeding alters field microclimate compared to land that is cultivated before seeding, especially during early stages of crop growth. This affects the structure and productivity of the plant at harvest (Cutforth and McConkey, 1997). Seeding directly into stubble conserves moisture, often resulting in less yield loss due to drought (Enz et al 1988, Brun et al., 1986). However, plant stand can be lower in direct-seeded systems (Vyn et al., 1998). The objective of this study was to compare the effect of three residue management treatments on plant density, pod clearance, maturity, and yield in a narrow-row bean production system in the Saskatchewan environment.

3.2.1.1 Materials and Methods

Experimental design

The Saskatoon site in 2000 was situated on a black clay soil. The Rosthern sites in 1999 and 2000 were situated on black clay to clay loam soils. The experimental design was split-plot with residue treatments as main plot and cultivar as sub-plot. Four and eight replicates were used in 1999 and 2000 seasons respectively. Main plot sizes were 19.5m by 18m in 1999 and 9m by 12m in 2000. Sub-plot sizes were 9.6m by 18m in 1999 and 1.8m by 12m in 2000. In 2000, there was a border space 4.5m wide separating the two sub-plots of one main plot from the two sub-plots of another main plot within a block. Spring wheat stubble height in these field experiments varied from 0.20 to 0.25 m. The three residue treatments were cultivated, mowed and stubble. The cultivated treatment was cultivated to a depth of approximately 10 cm using a field cultivator and then harrowed. In the mowed plots, stubble was cut at ground level with a sickle mower and the cut stubble fell where it was cut. No treatment was applied to the stubble treatment, so that standing stubble was left over the soil surface before and after seeding. Residue management treatments were applied 1 to 3 days before seeding. CDC Expresso and CDC Nighthawk dry bean cultivars were chosen to investigate the effect of tillage systems on specific bean growth types. CDC Expresso is a black bean cultivar with a determinate bush growth type. CDC Nighthawk is a black bean cultivar with an indeterminate bush growth type. Both cultivars were commonly used in narrow-row bean production cultivars when this experiment was initiated.

Field procedures

The target plant densities were 50 plants m^{-2} and 55 plants m^{-2} in 1999 and 2000, respectively, in a 21 cm row spacing. Bean seed was treated with carbathiin and thiram (formulated as Vitaflo-280) for the 2000 season because of poor emergence the previous year. All sites were seeded between May 30 and June 3 in 1999 and 2000.

Fertiliser was applied during seeding as a band below and to the side of the seed row. In 1999, N and P were applied at a rate of 5 kg ha^{-1} and 22 kg ha^{-1} as ammonium phosphate (11-51-0). In 2000, fertiliser was applied at rates of 84 kg ha^{-1} of N and 28 kg ha^{-1} of P as urea (46-0-0) and ammonium phosphate (11-51-0). Granular bean inocculum (Microbiorhizogen Corporation, Ltd., Saskatoon, SK) was placed in the seed row during the seeding operation at a rate of 5 kg ha^{-1} in both years.

Chemical weed control in 1999 consisted of post-seeding application of glyphosate (2.5L/ha rate), post-emergent application of clethodim (0.37 L/ha) and an application of bentazon (2.25 L/ha) after the second trifoliate leaf stage in bean. For the 2000 growing season, commercially formulated granular ethalfuralin was broadcast in the fall of 1999 (21.5 kg/ha) in preparation for the 2000 experiment. Two applications of bentazon were made (rate of 2.25 L/ha) after the second trifoliate leaf stage and before flowering. Grassy weeds were controlled by post-emergent application of clethodim (Select) at 0.37 L/ha.

Sampling and measurement procedures

Initial plant densities (plants m^{-2}) were determined for each sub-plot from 4 and 8 meters of row in 1999 and 2000 respectively. Date of flowering was not evaluated for each plot in 1999. Date of first flower was determined in 2000 by identification of any open flower within a subplot. Three biomass samples of 1m rows were collected from each sub-plot for Rosthern in 1999 around physiological maturity. Biomass of CDC Expresso and CDC Nighthawk was collected on Sept 2 and Sept 8, respectively, in 1999 in Rosthern. Internode lengths were evaluated in 1999 from these samples. Three biomass samples of 2m rows were collected from each sub-plot for Saskatoon and Rosthern locations in 2000 around physiological maturity. Biomass of CDC Expresso was collected on Aug 28 and 29 in Saskatoon and Sept 1 and 5 in Rosthern for 2000. Biomass of CDC Nighthawk was collected on Sept 8 and 11 for Saskatoon and Sept 15 and 26 for Rosthern. In 2000, lengths of the first five internodes, percentage pods at physiological maturity and plant density were evaluated for all plots and both locations. Pod maturity ratings for two replicates of the CDC Nighthawk variety in Rosthern were not available because they were badly damaged by frost before biomass samples were taken. The rest of the samples were evaluated based on a visual rating of full colour development of the bean seeds.

Three and four plants with intact cotyledonary nodes and symmetrical branching from the unifoliate node were evaluated from each biomass sample for 1999 and 2000 respectively. A total of 9 and 12 plants were measured in 1999 and 2000, respectively, within each sub-plot. The first internode was considered as the space between the cotyledonary node and the unifoliate leaf node.

Sub-plots were harvested with a small plot combine in both 1999 and 2000. In 1999, plots were harvested on Oct 9 in Rosthern, which was 128 days after seeding. The harvested area was between 39.9 and 42.6 m^2 in 1999. In 2000, plots were harvested on

Oct. 2 and 3 in Rosthern and Saskatoon, respectively, which was 123 and 128 days after seeding. The harvested area was 11.8 m^2 in 2000. Weights of yield samples were determined after drying and cleaning out soil and weed seeds. Average seed weight was determined from the weight of 200 seeds after cracked seeds were removed. Also, the weight of immature, off-colour seeds was measured from a sample of at least 130 g. The percentage immature seed was simply calculated as a percentage of the total. Seeds m^2 was calculated from individual seed weight (g $seed^{-1}$) and yield (g m^{-2}).

Weather, soil temperature and moisture measurement procedures

A CR10 data logger was used to record maximum and minimum soil temperatures (10 cm depth) in both years. These measurements were taken in one and two replicates in 1999 and 2000. The Saskatoon site in 2000 lost power and data are not available. In 2000, volumetric soil moisture was evaluated periodically throughout the growing season with Time Domain Reflectometry (Trase System 1, 6050X1, Soil Moisture Equipment Corp., Goleta, CA, USA). Pairs of steel rods 30 and 60 cm in length were driven into the soil in the seed rows. Also, at the time of measurement, 15 cm steel rods were inserted near the other rods and within a seed row. Measurements were taken on June 21, July 19, and August 4 in Saskatoon and on June 8 and 21, July 19, and August 2 in Rosthern. Time Domain Reflectometry (TDR) was used to measure the volumetric water content of the soil in 6 of the 8 replicates of each main plot between the two sub-plots. Attempts to measure soil moisture at 60 cm failed in the spring and early summer because of the high soil volumetric water content at that depth.

Analysis

The Proc Mixed procedure of SAS (version 8.0, Sas Institute Inc., Cary, NC, USA) was used for analysis of variance. Data for 1999 and 2000 were analysed as a split-plot design. Sites for 2000 were combined and analysed together with locations considered random in the model. Individual locations were also analysed separately. When F-tests indicated significant differences at the 0.05 probability level for treatment and treatment interaction means, least significant differences (LSDs) were calculated from the standard error of the difference between means. Means for residue treatments, cultivars, and residue treatment by cultivar interaction were separated using their respective LSDs and letters are used to annotate significant differences.

3.2.1.1 Results and Discussion

The Saskatoon data from 1999 was not used in the analysis because of production problems and high variability.

Precipitation was more than adequate in the summer of 1999 and poor soil aeration may have reduced plant growth during and after emergence. Weed control was not satisfactory in 1999. A killing frost in Rosthern on Sept. 11, 2000 occurred before the beans had reached physiological maturity. The percentage of immature seed in the

yield sample was evaluated after harvest. The later maturing cultivar, CDC Nighthawk, was most affected by frost.

Differences in average soil temperature among residue treatments were not consistent over the two years (Table 1). Soil moisture was not significantly affected by residue treatments in 2000 for either Saskatoon or Rosthern (Table 2).

Residue treatment affected plant density only in 1999 at Rosthern (Table 4). The plant densities achieved were lower than the recommended density of 45 plants m^{-2} (Saskatchewan Pulse Growers, 2000). The cultivated treatment had lower average plant density than the mowed or stubble treatments. Since there was a significant difference in plant density and no significant difference in yield among residue treatments, plant density reductions with cultivation were not detrimental to yields. Neither tillage treatment nor cultivar affected plant density in 2000.

In Saskatoon, 2000, the cultivated treatment required 2.8 fewer days to first flower than did the mowed treatment (Table 3). In Rosthern, 2000, the stubble treatment required 1.1 fewer days to first flower than the mowed treatment, but neither were different from the cultivated treatment. When locations were combined there was no significant difference among residue treatments. CDC Expresso required 9.8 fewer days to first flower than CDC Nighthawk did when locations were considered together. The cultivated treatment seemed to have a greater effect on CDC Expresso in reducing days to first flower than it did on CDC Nighthawk (Table 3). Perhaps with the indeterminate cultivar, CDC Nighthawk, determination of days to first flower is less affected by the microclimatic conditions associated with the cultivated treatment than is CDC Expresso.

We found no internode length response to residue management treatments. If there was a residue effect on the average length of the lower internodes, the net effect was not large enough to be statistically or agronomically significant in this experiment over each of three site-years (Table 3). There were differences in average internode length between cultivars in all three site-years. There was, however, a residue treatment by cultivar interaction in Rosthern in 2000. The difference between the two cultivars was much smaller for the stubble treatment than for mowed or cultivated treatments, suggesting that the response of dry bean to standing stubble was not in effect with the determinate cultivar, CDC Expresso.

Standing stubble had little or no effect on pod clearance (Table 4). In Saskatoon, 2000, pod clearance was significantly higher for the stubble treatment than for the cultivated treatment. Alternatively, pod clearance was affected by residue treatment in Rosthern, 1999, such that the cultivated treatment had significantly higher clearance than the uncultivated treatments. The difference was relatively small (6.3 %) and does not appear to be related to plant density (Tables 4 and 5). There was no difference in pod clearance between stubble and cultivated treatments for Rosthern, 2000. In is interesting to note that in two of three site-years the mowed treatment had the lowest pod clearance. Since the effects of cultivated and stubble treatments are not at all consistent over locations and years, a judgement on the effect of stubble height on pod clearance must be reserved until more research has been completed.

There were no differences between residue treatments in 1999, even though there were significant differences in plant density in that year (Table 5). However, a significant cultivar by residue treatment interaction occurred, likely reflecting differences in cultivar maturity and growth type. For the 2000 season, average yield for two

locations was significantly lower for the mowed treatment than for the cultivated or stubble treatments (Table 5). There was no significant difference in yield between the cultivated and stubble treatments in either location or when locations were combined. There was no cultivar by residue treatment interaction in this year. CDC Nighthawk had significantly lower yield than CDC Expresso in the Rosthern location only.

There were no differences in the percentage of immature seeds at grain harvest between the residue treatments in 1999 (Table 5). These differences in percent immature seeds reflect differences in yield for Rosthern in 1999 (Table 5). Therefore, delayed maturity may have contributed to yield losses in the stubble and mowed treatments with CDC Nighthawk. In 2000, residue treatments significantly affected the percentage of immature seeds in the yield sample when locations were considered separately (Table 5). The mowed treatment was generally of the poorest quality. There was no significant difference between the cultivated and stubble treatments for immature seeds in either location.

Discussion

Soil temperature and moisture differences among different residue treatments may be spatially consistent in the absence of vegetation, but the addition of bean plants confounds these effects on moisture and temperature though water use and shading (Table 1). Since the bean plots were not uniform in density in any site-year, high spatial variability in soil parameters is to be expected. If there were no significant moisture differences during the period prior to canopy closure, soil temperatures would simply vary more over the day with a bare surface compared with a residue-covered surface (Hay et al. 1978, Weirenga et al. 1982). If residue treatments are applied in the previous fall or they are long-term tillage treatments, temperature differences may be greater. Soil temperature and moisture differences are often evident with mouldboard ploughing (Arshad and Azooz 1996, Hay et al.1978, Johnson and Lowery 1985), but would probably be less pronounced with shallow cultivation. No conclusion as to the effect of different residue treatments on soil temperature can be made in this experiment other than that variability is high.

The small soil temperature increase that we observed with the cultivated treatment probably caused the bean crop to mature faster. However, the higher soil temperatures often associated with tillage may actually be detrimental to yield in situations in which maturity is not a limitation to yield. The temperature optimum for vegetative growth may be higher than for reproductive growth and yield of dry bean. The rapid, early growth often associated with cultivation may deplete soil water and nutrients so that yields and harvest index are sometimes lower in cultivated plots compared with direct-seeded plots for some warm season crops. Doran (1984) reported that higher soil water storage in early summer with the residue-covered soil was associated with an increase in yield compared with a bare, uncultivated soil. The effect of the higher early biomass production on final seed yield depends on the availability of water later in the growing season. In Saskatchewan, where terminal drought during pod filling is common, this "haying off" effect may become an important factor in determining good residue management practices.

Table 1. Average soil temperatures from 10 cm depth for three residue treatments.

	Average Soil Temperature		
Rosthern 1999[a]	June	July	August
Cultivated	16.1	18.0	17.0
Mowed	15.6	17.6	17.2
Stubble	15.5	17.4	17.0
Rosthern 2000			
Cultivated	15.3	18.5	16.6
Mowed	15.4	18.0	16.2
Stubble	14.8	18.8	16.2

[a] Measurement starting 6 June for 1999 only.

1.1.1 Soil Moisture

Soil moisture levels are often higher when residue insulates the soil surface, but plant uptake also affects moisture levels in the soil. Plant uptake and protection of the soil by the plant canopy become the dominant factors affecting the moisture content of the soil over the growing season. With an important growing season limitation, a reliable, meaningful measure of water use efficiency is difficult to calculate from water use and yield of dry bean. Calculation of water use efficiency differences among residue treatments for dry bean is complicated by the effect of maturity and harvest losses on final yield. However, a project by Cutforth and McConkey (1997) demonstrated that the presence of standing stubble could improve yields and water use efficiency in water-limited environment. Potential evaporation was also reduced during the early growth of the spring wheat crop, likely because of decreased wind speeds and soil temperatures during that time. Therefore, although it may be difficult to measure water use efficiency for bean in this environment, water use efficiency is probably increased in residue-covered soils.

Plant density

Residue management did not affect plant density at either location in 2000. This observation agrees with the results of several experiments (Deibert and Utter 1989, NeSmith and McCracken 1994). To my knowledge, no other researchers have observed a significant reduction in plant density with cultivation or ploughing compared with

direct-seeding during an uncommonly wet spring. There is no question that this did occur in 1999 in Rosthern. It is possible that the reduction in plant population was caused by a tillage interaction with either a fungal pathogen or other soil biota. Excess compaction in the seed row and resultant aeration difficulties may have been a factor in the development of disease and poor emergence in cultivated plots. Fusarium root rot (*Fusarium solani* f. sp. Phaseoli) increases with increases in soil temperature (Miller, 1985b), however, poor aeration and compaction also contribute to development of the disease (Miller, 1985a). If soil temperatures were somewhat higher and drainage was reduced in the cultivated treatment, fusarium root rot could have caused a decline in emergence in the wet spring of 1999. Whatever the cause, we are not suggesting that

the inherent nature of the seed bed was the cause of the difference in emergence, but rather that an interaction with a biotic factor occurred during an atypical spring and summer.
It is important that the soil texture and density considered when considering a residue management strategy. If the soil is not well suited to no-till production of other crops, it will probably be even less suitable for no-till production of bean. If a producer has seeding equipment that effectively places other crops below the residue, there should be no obstacles to seeding bean either, providing the seeder is equipped to not damage the seed when delivering the beans to the seed bed (Vandenberg, 1990).

Table 2. Volumetric soil moistures for cultivated, mowed and stubble treatments over three dates in Saskatoon and four dates in Rosthern.

		0 – 30 cm depth			
	Date	Cultivated	Mowed	Stubble	LSD
Rosthern	June 8	23.9	23.4	25.2	ns
	June 21	29.3	29.3	29.4	ns
	July 19	26.1	26.5	26.8	ns
	Aug. 4	15.8	18.0	17.3	ns
	Average	23.8	24.3	24.7	ns
Saskatoon	June 21	32.5	34.1	33.8	ns
	July 19	31.5	34.6	33.3	ns
	Aug. 4	36.2	24.0	24.1	ns
	Average	33.4	30.9	30.4	ns

[z] Means within columns and groups are separated using LSD. Letters indicate significant differences among means ($p<0.05$).

Maturity

We found that the treatment with the most surface residue had the lowest quality of seed when harvested at maturity. Seed quality is important for determining dry bean price because beans are primarily sold as a whole seed to the edible market. We found differences in the amount of seeds in the yield samples that were immature and off-colour, probably the result of frost damage to the plants. The stubble treatment did not significantly reduce yield quality compared with the cultivated treatment. The percentage of immature seeds was higher in the mowed treatment than the cultivated treatment for both Saskatoon and Rosthern in 2000, presumably because of a difference in maturity when frost ended the growing season. Some of the bean-tillage research has been conducted with snap beans and therefore seed immaturity and terminal frost damage is not an issue in these experiments (Mascianica et al. 1986, Bellinder et al. 1983, 1987, Mullins et al. 1980, 1988, NeSmith and McCracken 1994, Skarphol et al. 1987).
There was little evidence for a difference in maturity between cultivated and stubble treatments in this experiment but there was a difference between the mowed and cultivated treatment (Table 3). Maturity seems to be advanced with a decrease in surface residue, but development and use of bean cultivars with shorter time to maturity will reduce the risk of frost damage associated with direct-seeded beans.

Table 3. Average days to flower and pod maturity for three residue treatments and two bean cultivars.

Year	Factor	Treatment	Days to Flower	Pod Maturity
			—d—	—%—
Saskatoon 2000	Residue	Cultivated	52.5 b	52 a[z]
		Mowed	55.3 a	24 b
		Stubble	54.1 ab	34 b
		LSD (0.05)	2.0	16
	Cultivars	Expresso	50.1 b	-
		Nighthawk	57.7 a	-
		LSD (0.05)	0.8	-
Rosthern 2000	Residue	Cultivated	55.9 ab	27
		Mowed	56.6 a	20
		Stubble	55.5 b	30
		LSD (0.05)	0.8	ns
	Cultivars	Expresso	47.5 b	-
		Nighthawk	59.6 a	-
		LSD (0.05)	0.6	-

[z] Means within columns and groups are separated using LSD. Letters indicate significant differences among means ($p<0.05$).

Internode length and pod clearance

We expected differences in internode length caused by differences in the residue treatments. Perhaps the wind speed differences among 25-cm tall wheat residue treatments were not large enough to affect internode length. Although literature supports a role for standing stubble in increasing crop height and harvest efficiency (Huggins and Pan 1991, Cutforth and McConkey 1997, Bellinder et al. 1983 and 1987, Mascianica et al. 1986), it has proven not to be the case in this experiment (Table 4). The lack of a clear stubble height effect on internode length and pod clearance in this experiment may also reflect spatial and temporal variability in plant emergence within plots. Beans were not placed uniformly in the seed row by the seeder in both years of this experiment. Plant density affects the height and pod clearance of bean (Ablett, 1988). With a more uniform stand of beans, there may be an effect of stubble height on internode length and pod clearance of bean in the absence of plant density effects.

Most of the currently published research studying the effect of residue management on the internode length and pod clearance has been for snap bean. There are few reasons that these effects would not apply to dry bean as well. The standing stubble effect on pod clearance and internode length may be more pronounced with indeterminate cultivars. I

Table 4. Average plant density, internode length and pod clearance for three residue treatments and two bean cultivars.

Year	Factor	Treatment	Plant Density	Internode Length	Pod Clearance
			plants m^{-2}	— cm —	— % —
1999	Residue	Cultivated	20.7 b [z]	2.26	79.4 a [z]
		Mowed	30.2 a	2.73	72.7 b
		Stubble	33.0 a	2.32	73.1 b
		LSD (0.05)	7.1	ns	5.3
	Cultivars	Expresso	26.5	2.73 a [z]	76.7
		Nighthawk	29.4	2.15 b	73.5
		LSD (0.05)	ns	0.57	ns
Saskatoon 2000	Residue	Cultivated	37.1	54.2	80.4
		Mowed	36.5	55.8	78.0
		Stubble	40.0	54.8	84.9
		LSD (0.05)	ns	ns	ns
	Cultivars	Expresso	26.5	50.0 b	81.5
		Nighthawk	29.4	59.8 a	80.7
		LSD (0.05)	ns	7.2	ns
Rosthern 2000	Residue	Cultivated	37.1	54.2	80.4
		Mowed	36.5	55.8	78.0
		Stubble	40.0	54.8	84.9
		LSD (0.05)	ns	ns	ns
	Cultivars	Expresso	26.5	50.0 b	81.5
		Nighthawk	29.4	59.8 a	80.7
		LSD (0.05)	ns	7.2	ns

[z] Means within columns and groups are separated using LSD. Letters indicate significant differences among means ($p<0.05$).

suspect that the effect would depend on the growth type of the bean (i.e. indeterminate vs. determinate and upright vs. prostrate) and therefore this increase in internode length may not be expected in all cultivars of dry bean or snap bean. However, a determinate, upright cultivar of snap bean, Provider, was used in the snap bean experiment by Mascianica et al. (1986) that observed increased peduncle height and harvest efficiency. CDC Expresso was also a determinate, upright cultivar but it did not respond in the same way to standing stubble as did Provider snap bean.

Table 5. Average seed weight, seeds per area and yield for three residue treatments and two bean cultivars.

		Treatment	Seed Density	Seed Weight	Yield	Immature Seeds
			seeds m^{-2}	g (1000 seeds)$^{-1}$	— kg ha^{-1} —	— % —
Rosthern 1999	Residue	Cultivated	395	159.9	589	20.1
		Mowed	424	154.6	656	19.7
		Stubble	443	152.6	686	18.5
		LSD (0.05)	ns	ns	ns	ns
	Cultivars	Expresso	473 a	170.2 a	712 a	13.9 b
		Nighthawk	368 b	141.3 b	574 b	25.0 a
		LSD (0.05)	51	9.8	23	6.8
Saskatoon 2000	Residue	Cultivated	589	176.3 a [z]	1045 a	1.3 b
		Mowed	520	165.9 b	857 b	3.9 a
		Stubble	574	168.4 b	989 a	1 6 b
		LSD (0.05)	ns	8.7	125	1.9
	Cultivars	Expresso	507 b	182.1 a	946	1.3 b
		Nighthawk	615 a	158.3 b	981	3.2 a
		LSD (0.05)	46	3.4	ns	0.9
Rosthern 2000	Residue	Cultivated	542 a	154.3	902 a	17.0 b
		Mowed	446 b	150.0	727 b	30.1 a
		Stubble	505 a	157.5	855 a	24.0 ab
		LSD (0.05)	54	ns	113	9.3
	Cultivars	Expresso	502	172.7 a	933 a	9.9 b
		Nighthawk	494	135.2 b	723 b	37.5 a
		LSD (0.05)	ns	6.4	70	5.8

[z] Means within columns and groups are separated using LSD. Letters indicate significant differences among means ($p<0.05$).

Pod clearance at seed harvest may depend partly on the diameter of the main stem as well as on basal internode length. After natural maturation or frost desiccated the crop, the bean plants appear to have 'settled' with a concomitant reduction in pod clearance. The reduced wind speed conditions inherent in standing stubble may increase internode length by reducing stem diameter. The diameter of the main stem may be less important for determining pod clearance at snap bean harvest, since the plants have not been

desiccated. Therefore, while pod clearance and internode length may be positively related before physiological maturity, when snap beans are harvested, they may be inversely related at the time that dry bean is mechanically harvested. Obviously, there is a need for research of the effect of stubble height on the early growth of dry bean and on dry bean harvest efficiency.

Yield

The effects of the residue management treatments on yield are variable over years (Table 5). Cultivated and stubble treatments were not significantly different in any site-years when cultivars were considered together, since differences in 2000 were less than 5% of the average yield. Several other studies have shown that direct-seeding did not significantly reduce yield (Bellinder et al. 1987, Diebert 1995, Skarphol et al. 1987, Mullins et al. 1980). Since the mowed treatment had the highest percentage of immature seeds and the lowest yields in 2000, this treatment is judged to be the least ideal residue management option. Since the only difference between the stubble treatment and the mowed treatment was the position of residue, we must conclude that a large amount of surface residue was detrimental to yields in this experiment and in other studies. Soybean seed yield was negatively correlated with surface residue cover is a study by Vyn et al. in Ontario (1998). Soybean on no-till plots that were not baled emerged later than when residue was baled. No tillage reduced soybean yields by 29% when residue was baled and by 8% when not baled compared with high disturbance treatments. This observation supports the conclusion that vertical orientation of the stubble is less detrimental to yields than surface orientation.

Treatment differences in yield appear to be due to differences in the number of seeds produced per unit area rather than to differences in seed size. Seeds m^{-2} follows the same pattern as yield for 2000 (Table 5). Seed weight did not cause the differences in yield among residue treatments, since there were no significant differences in 1000 seed weight due to residue treatment (Table 5). Several researchers have found that stubble treatments had little effect on seed weight of dry bean and soybean (Croissant et al. 1991, Deibert 1989, Webber et al. 1987, Saindon et al. 1995). Webber et al. (1987) found that seeds per pod and pods per plant, and not seed weight, were most affected by tillage treatments and were the cause of observed differences in yield. The yield differences that we observed appear to have been determined before the fall frost occurred when seed number per plant was determined. Soil moisture and temperature data were highly variable, probably because of spatial and temporal variability in plant emergence and density within plots. Although there were no consistent or significant differences in soil temperature or moisture due to residue treatments, the residue treatments did affect the yield and maturity of dry bean. The effects of residue treatments on yield varied over the two years of the experiment, probably because of improvement in seeding equipment, weed management and fertility in 2000. In 1999, there were no significant differences among residue treatments. However, in the 2000 season, the mowed treatment had the lowest yield of the three residue management treatments. It also had a higher percentage of immature seeds than the cultivated treatment. We suspect that this is because of a difference in flower, pod, and/or seed abortion due to maturity differences between the three residue treatments.

The mowed treatment had delayed maturity, which led to frost damage to seeds and yield loss when an early frost occurred. Judging from days to flowering, pod maturity, and percentage immature seeds, the stubble treatment delayed maturity less than the mowed treatment and was generally not significantly different from the cultivated treatment. While it is true that part of the observed delay in maturity in direct-seeded treatments could be attributed to delays in germination due to seed placement difficulties in 2000, a cool seedbed likely contributed to the delay in maturity as well. In general, while there may not be evidence of a yield decrease caused by the stubble treatment, direct-seeding into thick surface residue would probably increase the risk of frost damage to maturing seeds.

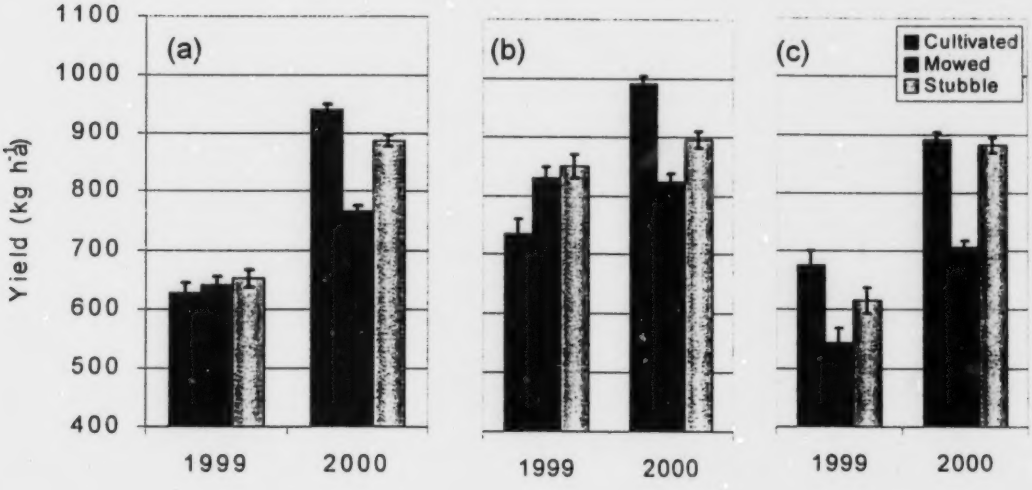

Figure 1. Yields of dry bean from 1999 (Saskatoon) and 2000 (Saskatoon and Rosthern): (a) mean yields averaged over cultivars, (b) mean yields for CDC Expresso, (c) mean yields for CDC Nighthawk. Bars are +/- standard error of the means.

The mowed treatment was intended to be intermediate to the cultivated and stubble treatments. While it was true that the mowed treatment lacked standing stubble and yet was undisturbed by cultivation, the crop growth response did not seem to depend on the presence of standing stubble so much as the amount of surface residue. We found no consistent differences among residue treatments for either internode length or pod clearance. Thus, the stubble treatment was actually intermediate in the factor that seemed to influence crop growth the most. The stubble treatment had less surface residue than the mowed treatment and more than the cultivated treatment. The amount of surface residue associated with each residue management treatment was a factor when the

presence of a thick layer of residue interfered with seed placement during seeding with a double-disc type seeder in 2000. Through this indirect effect, the time for complete emergence was lengthened and maturity was delayed.
Plant density differences were non-significant in 2000. Yields were 941, 766, and 888 kg ha-1 for cultivated, mowed and stubble treatments respectively and all differences were significant (Fig 2a). The difference in yield between C and S treatments was small (5.6%) but statistically significant. The residue treatment by cultivar interaction was also significant (Fig 2b,c). The higher surface residue conditions of the M treatment seemed to be detrimental to seedling vigor and development in both cultivars.

3.2.2 The effect of nitrogen fertilizer on yield and nitrogen fixation in dry bean

Nitrogen fertilizer is currently not recommended for dry land, dry bean production in Saskatchewan. However, there is evidence that dry beans may benefit from application of fertilizer nitrogen as many areas that produce dry beans including Manitoba, North Dakota, Ontario, Michigan and Colorado, recommend the addition of nitrogen fertilizer to dry beans. The objective of this research was to quantify the effect of nitrogen fertilizer on the yield of dry beans grown under dry land conditions in Saskatchewan.

3.2.2.1 Materials and Methods

The experiment was a three factor, factorial RCBD conducted at Saskatoon, Rosthern and Melfort, Saskatoon in 1999. In 2000 a 100 kg ha^{-1} treatment was added and the locations of Redvers and Canora were included.The variables included variety, nitrogen rate and inoculation. Prior to seeding nitrogen fertilizer was banded at a rate of 0, 25, 50 and 75 kg ha-1. The beans were planted in 30 cm rows at a target density of 60 plants m-2 with and without granular inoculum in the seed row. Two varieties were seeded, CDC Expresso, a type I black bean and CDC Camino, a type I pinto type.

3.2.2.2 Results and Discussion

3.2.2.2.1 Rhizobium inoculation

Overall there was no significant yield response to inoculation with granular rhizobium. In 1999 there was not a significant yield response to rhizobium at any locations. The Melfort site appeared to have a significant response to inoculation but this was because of the unbalanced design that was used there. In 2000 the method by which we applied the granular rhizobium was changed to reduce cross contamination between plots. In 2000 Rosthern was the only site of the five locations to have a significant yield increase from inoculation. In 2000 there was an inoculation x nitrogen rate interaction (Figure 2). At 0 and 25 kg ha-1 of applied N there was an average increase in yield of 81 kg ha^{-1} by inoculating but there was no yield increase at N rates above 25 kg ha^{-1}. Assuming that beans sell for $0.25 per pound inoculating at low rates of N will result in $9.36 per acre greater gross return (Figure 3). It is important to note that these benefits form inoculation do not occur when over 25 kg ha^{-1} of N are applied. In 2000 the highest net returns occurred at a N rate of 25 kg ha^{-1} and with rhizobium.

Overall there was no evidence of a variety by rhizobium yield interaction. Only at Rosthern in 2000 was there was a significant inoculation by variety interaction where CDC Expresso benefited from inoculation but not CDC Camino.

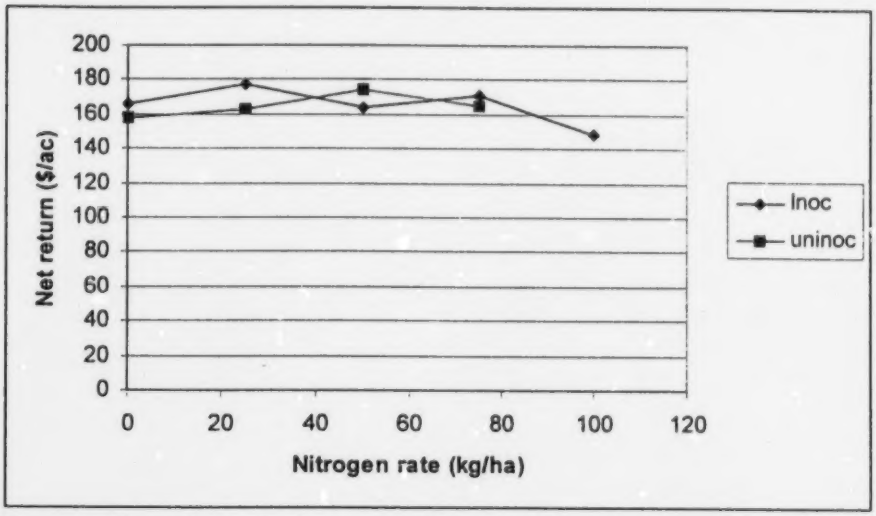

Figure 2. The effect of nitrogen fertilizer and inoculation on dry bean yield over five locations in 2000.

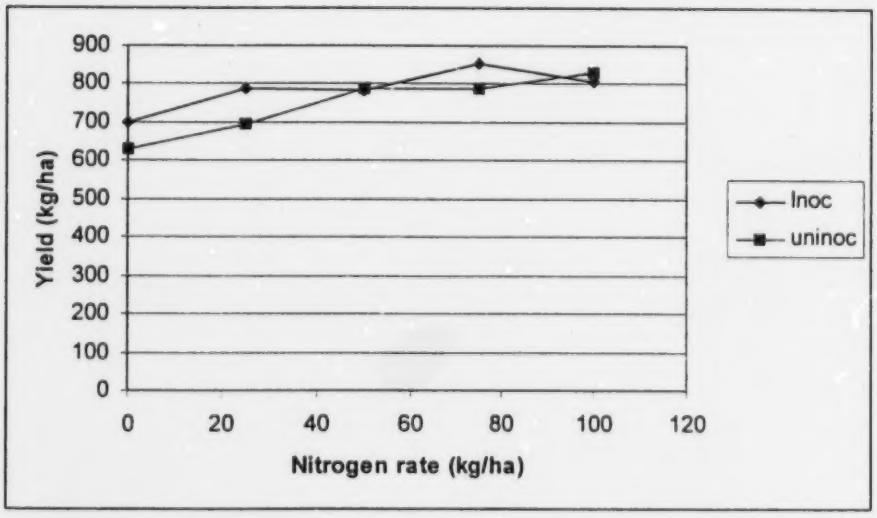

Figure 3. The effect of nitrogen fertilizer and inoculation on returns over five locations in 2000.

3.2.2.2.2 Nitrogen Fertilizer

Overall there was a yield increase from using nitrogen fertilizer in both years (Figure 4). Nitrogen fertilizer resulted in yield increases in significant yield increases in six of the eight site years. In 1999 all three locations had a positive response to nitrogen fertilizer (Figure 5). Dry bean had a significant response to the addition of nitrogen fertilizer at all three locations with the exception of Expresso at Rosthern. At Rosthern the proximity of the nitrogen fertilizer band to the seed row resulted in very low rates of emergence giving non-typical responses, therefore the data is not discussed further. Adding 75 kg ha^{-1} on nitrogen increased the bean yield by an average of 40 %. The year 2000 saw similar results to 1999 at Rosthern, Saskatoon and Melfort (Figure 6). Nonetheless, the beans grown in Canora and Redvers did not have a significant response to nitrogen fertilizer, probably the result of the low yield potential at these sites caused by an early frost and poor soil conditions, respectively.

Despite the modest yields that were observed in this study, it was still economically advantageous to add nitrogen fertilizer up to a rate of 75 kg ha^{-1}. This analysis assumes that the actual cost of nitrogen was $0.40 per pound and the price of beans was $0.25 per pound. The maximum net return was obtained by adding 50 kg ha^{-1} (44 lbs $acre^{-1}$) of actual N but the average increase in net returns was only $7.50 $acre^{-1}$ at this rate. Nonetheless, additions of nitrogen did result in a net return that can be substantially higher under good growing conditions.

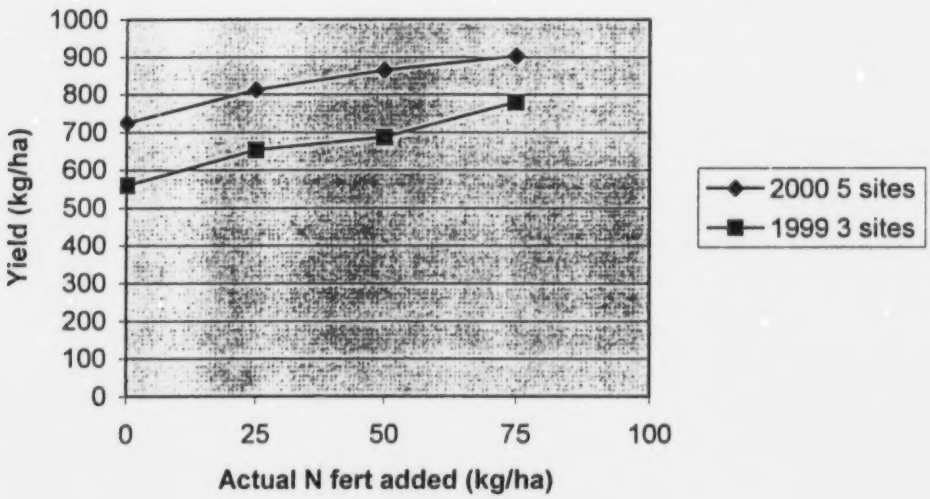

Figure 4. Average yield increase of dry beans from nitrogen fertilizer for 1999 and 2000.

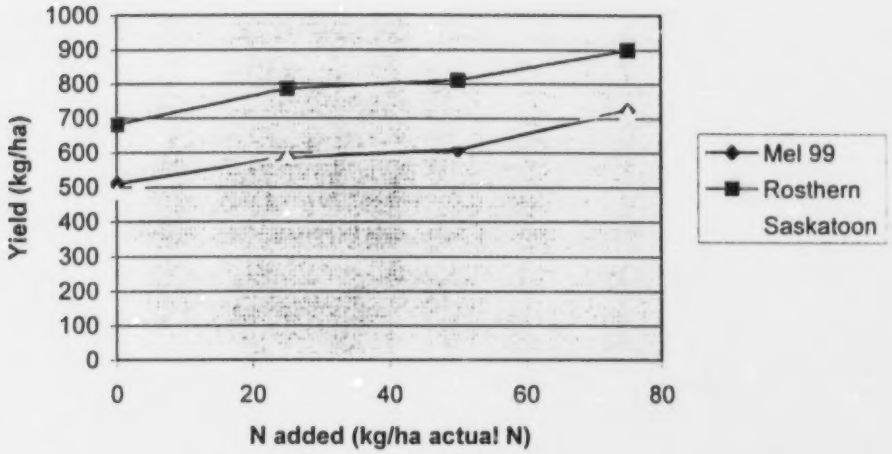

Figure 5. The effect of nitrogen fertilizer on dry bean yield, 1999.

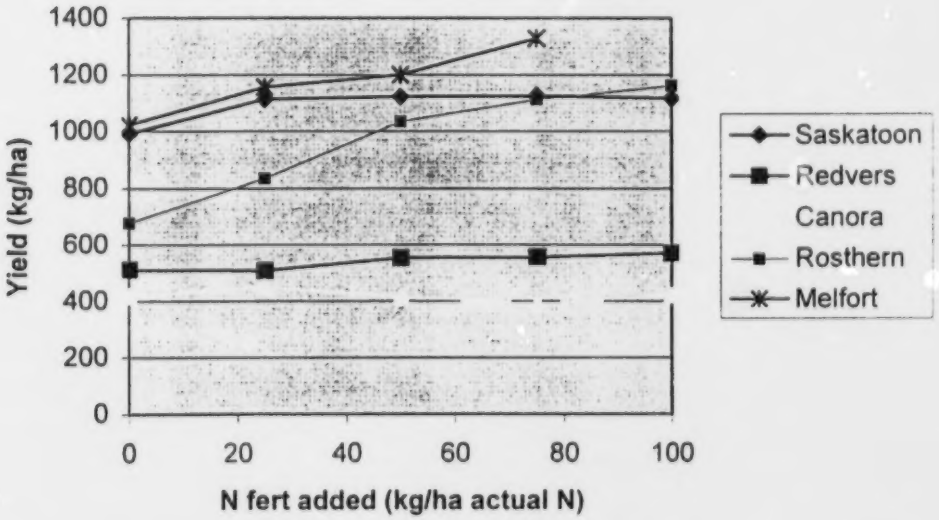

Figure 6. The effect of nitrogen fertilizer on dry bean yield at five locations, 2000.

The positive yield response to nitrogen fertilizer in this study is similar to that observed by Liebman et al. (1995) who found a positive yield response to nitrogen under two different tillage systems. Blaylock (1995) observed that nitrogen fertilizer increases the yield of navy bean. Although the effect was not consistent, a tentative recommendation would be that producers in Saskatchewan should add nitrogen fertilizer to their dry beans. The interaction between rhizobium inoculation and N fertlizer is complex. Producers should also inoculate their beans with rhizobium if they are applying low amounts of fertlilizer nitrogen.
Adding nitrogen fertilizer did not affect the amount of seeds that were frost damaged. As both years of this study saw significant frost damage (average of 7.5%), a N fertilizer effect on seed maturity should have become apparent if it exists. However, because there was no effect of N fertilizer on maturity, there may be no negative production risks associated with adding nitrogen fertilizer other than the increased risk of white mould.

3.2.2.2.3 Nitrogen Fixation

Because of problems in the N-15 processing we are still awaiting retesting some samples before a complete report can be filed on the effect of nitrogen fixation. Preliminary results suggest that nitrogen fixation in dry bean occurs at a very low level (<20%). The addition of nitrogen fertilizer reduces but does not eliminate nitrogen fixation. Extra N can increase the pod clearance in dry bean but this is not always significant. The amount of nitrogen fixation in the dry beans was low and variable. Nitrogen fixation generally decreased with increased amounts of fertilizer nitrogen being added, however it did not eliminate N fixation.

3.2.3 The effect of harvest technology on harvest efficiency

The objective of this experiment was to determine the effect of Rake up crop lifters on harvest losses while straight combining dry beans. The combine treatment were performed on the seeding system trial located at Saskatoon using CDC Expresso and CDC Nighthawk beans. The Rake up lifters could not be installed in the recommended manner on the small plot combine resulting in the angle being steeper than intended. Under these conditions the rake up lifters reduced the harvested bean yield by 24%. This was because of a 39% increase in seed loss at harvest. These results are the opposite of what was expected and may be attributed to the modified installation on the plot combine. However, this effect may be real and therefore to verify this the lifters will be installed on a commercial combine next year. There was significant more yield loss in Expresso then there was in Nighthawk. This difference could be attributed to the taller growth habit of Nighthawk.

3.2.4 The effect of seeding rate on the yield of two dry bean cultivars

The recommended seeding rate for all dry bean market types and cultivars is 45 plants m^{-2}. However many other bean producing areas have a lower recommended seeding rate. The objective of this study was to determine the yield density relationships in two cultivars of dry bean and optimum plant population under solid seeded production system in Saskatchewan.

3.2.4.1 Materials and Methods

The area to be seeded was tilled and harrowed before seeding. P_2O_5 fertilizer was side-banded at 20 kg ha^{-1} actual P_2O_5. The dry bean was inoculated with a recommended granular rhizobium. Seeding and harvest dates are listed in Table 6. The beans were seeded using a seed drill with either a hoe or disk openers. Nitrogen fertilizer at 50 kg ha^{-1} actual N was side banded 2.5 cm to the side and 2.5 cm below the seed row.

Weed control was performed by using pre-plant ethafluralin (5% granular) at 11.3 kg/ha, and post-emergence bentazon (480g/L) at 1 L/ha was applied with Assist oil concentrate at 1% v/v at the second trifoliate stage. Registered grassy weed herbicides were applied at recommended rates and stages to control grassy weeds. Hand weeding supplemented chemical weed control to keep the plots weed free.

The beans were harvested using a small plot combine equipped with a straight header. Only the centre 1.5 m of each plot was harvested, leaving at least one guard row next to adjacent plots in all cases. Following harvest, the beans were cleaned and weighed and

Table 6. Seeding date, average percent emergence, date of first frost and harvest date for dry bean grown at locations in 1999 and 2000.

Year	Location	Seeding Date	Camino Average % Emergence	Expresso Average % Emergence	Inter Row Width (cm)	Harvest Date
1999	Saskatoon	June 4	88.0	62.6	30	Sept. 23
	Rosthern	June 5	70.0	42.4	30	Sept. 24
	Melfort	May 27	80.1	76.1	20	Sept. 21
2000	Saskatoon	May 29	37.8	54.2	20	Oct. 4
	Rosthern	June 2	26.8	54.4	20	Oct. 2
	Melfort	May 25	40.4	34.6	20	Sept. 25
	Canora	May 31	17.6	31.7	20	Oct. 5
	Redvers	June 6	24.1	45.8	20	Oct. 6

the thousand seed weight was determined on undamaged seeds. The percentage frozen seed was determined by visual inspection of 200 seeds per plot. Yields presented are based on 16% moisture content.

The experimental design was a factorial randomized complete block replicated four times, with cultivar and seeding rate as the factors.

Analysis

Data were analyzed using PROC MIXED of SAS (SAS Institute, Inc. 1991) with locations and years as random effects. PROC MIXED does not return significance levels for the random effects in the model. Nonetheless, emergence varied between locations and years, and there was variation associated with the year*cultivar, year*location*cultivar and year*seeding rate*cultivar. Therefore, non-linear regression analysis was performed on the relationship between dry bean yield and bean density for each cultivar at each location and year using the SAS NLIN procedure (SAS Institute, Inc. 1991). The following asymptotic equation (Silvertown and Lovett Doust, 1993) was used to determine the relationship between bean yield and density:

where Y is the seed yield in kg ha^{-1}, w_m is a fitted parameter which represents the

$$Y = w_m N / (1 + aN) \quad [1]$$

maximum potential yield per plant in kg ha^{-1}, N is the bean density in plants m^{-2}, and a is the area necessary to achieve w_m in m^2.

Differences between the non-linear response due to treatments were assessed using a sum of square reduction test (Tharp et al. 1999). The coefficient of determination (R^2) was approximated using the residual sums of squares for each regression using the following formula (Jasieniuk et al. 1999):

$$\text{Pseudo } R^2 = 1 - SS(\text{Residual}) / SS(\text{Total}_{\text{Corrected}}) \quad [2]$$

where SS(Residual) is the residual sum of squares and SS ($\text{Total}_{\text{Corrected}}$) is the corrected total sum of squares for the non-linear regression.

Economic analysis

The amount of seed (kg ha^{-1}) required to increase the plant density was calculated using the equation:

$$\Delta N = TSW / e \quad [3]$$

where ΔN is the change in plant density (plants m^{-2}), TSW is the thousand seed weight of the seed (g), and e is the proportion of all seed that emerges. As emergence is often low in large seeded pulse crops (Jettner et al. 1999; Saindon et al. 1995), an emergence rate of 70% was assumed for both cultivars. This rate includes both germination and emergence. The value of the harvested beans was determined by yield of the beans predicted from equation [1] times the selling price of beans (Table 7). The monetary return on increasing the seeding density was determined by taking the value of the harvested beans minus the seed costs necessary to achieve that plant density (equation 2). The seed costs include a 10% opportunity cost (French et al. 1994). The bean selling prices (Table 7) were obtained using averages for the years 1998-2000 (Denis Lange, personal communication,

May 8, 2001). The thousand seed weight for each cultivar (Table 7) was the value from the Saskatchewan seed guide (Saskatchewan Agriculture and Food, 2001c). The bean seed price was assumed to be 2.4 times greater than the bean selling price (Lief Andersen, personal communication, June 18, 2001).

Table 7. Three-year averages for 1000 seed weight and economic parameters for bean cultivars.

Cultivar	1000-seed weight (g)	Seed cost ($\$ kg^{-1}$)	Selling price ($\$ kg^{-1}$)
CDC Expresso	191	1.46	0.54
CDC Camino	323	1.41	0.47

3.2.4.2 Results and Discussion

3.2.4.2.1 Seedling Emergence

Seedling emergence was lower than expected and variable across locations and years (Table 6). Emergence ranged from 17.6% for Camino at Canora in 2000 to 88% for Camino at Rosthern in 1999 (Table 6). In 1999, Camino had greater emergence than Expresso whereas in 2000, Expresso had greater emergence than Camino. This interaction may be due to differences in the seed treatments. The 1999 Camino seed was treated with Captan seed fungicide (0.0028 l kg^{-1}) and an insecticide, whereas the Expresso seed was untreated. Nevertheless, both cultivars in 2000 were treated with the seed fugicide metalaxyl (0.0011 l kg^{-1}) yet there was still differential emergence between the cultivars (Table 6). The reason for this is unknown, although there could have been difference in the handling of the beans that accounted for differences in emergence as dry beans. For example, dry beans can be damaged through mechanical handling which can result in reduced emergence (Vandenberg, 1990). Within years and cultivars,1 the locations had differences in bean emergence. These differences probably occurred because of differences in land preparation that reduced emergence in some locations, most notably Canora. Other studies have reported low plant emergence in dry beans (Saindon et al. 1995; Ablett, 1988).

Table 8. The effect of bean cultivar and seeding rate on emergence, yield, frost damage and yield components. F values and significance of fixed effects calculated for the fixed effects using PROC MIXED of SAS.

		Emergence	Emergence	Yield	Seed weight	Seeds Plant^{-1}	Seed density	Frost damage
		plants m^{-2}	%	kg ha^{-1}	g 1000 seed^{-1}		seeds m^{-2}	%
Cultivar (C)	Camino	26.26	49.78	769.5	298.3	138.4	257.3	5.885
	Expresso	27.58	51.80	696.9	183.3	164.0	387.4	4.524
	P>F	0.9202	0.9258	<0.0001	<0.0001	0.4472	<0.0001	0.3773
	LSD (0.05)	NS	NS	182	21.5	NS	84.5	NS
Seeding Rate (SR) viable seeds m^{-2}	20	10.83	54.17	474.5	242.2	223.19	204.3	6.212
	30	18.59	61.97	581.2	218.0	174.92	264.1	no data
	40	21.83	54.50	676.7	243.0	158.78	291.8	5.233
	50	27.06	54.13	753.7	218.1	143.51	352.1	no data
	60	28.17	46.95	825.2	240.3	134.58	364.8	5.067
	80	36.89	46.11	857.4	246.7	112.22	381.2	4.714
	100	46.31	46.31	951.5	245.9	99.79	416.4	4.806
SR	*P>F*	0.0044	0.3914	<0.0001	0.4703	0.0138	<0.0001	0.4047
	LSD (0.05)[z]	14.1	NS	150.5	NS	67.7	80.5	NS
SR Linear	*P>F*	<0.0001	0.5033	<0.0001	0.0532	0.0003	<0.0001	0.0787
SR Quad.	*P>F*	0.8742	0.1459	0.0206	0.507	0.1151	0.00264	0.3832
C x SR	*P>F*	0.9987	0.6449	0.7556	0.9282	0.9624	0.0393	0.6289

[z] Least Significant Difference for the seeding rates is calculated for individual comparisons using PROC MIXED of SAS and returns a range of LSDs for different comparisons. The highest of these values is presented here; the lowest was always within 60% of the highest.

3.2.4.2.2Yield Density Relationship

The yield density relationship of both cultivars displayed an asymptotic yield density response in most environments where the yields were greatest at the highest density (Figure 7). However, at Saskatoon in 2000 the yield decreased at the maximum plant density for both cultivars, indicating a hyperbolic relationship (Wiley and Heath, 1969). In several environments, the densities achieved were too low for the yield to reach an asymptote. The cultivar Expresso appeared to approach a yield maximum only at Saskatoon and Redvers in 2000.

Several other studies have demonstrated that determinant bush type bean cultivars have the highest yields at higher plant densities. Blackshaw et al.(1999) found in Alberta that, increasing the bean density of two determinate bush type beans from 24 to 48 plants m^{-2} increased yield an average of 36% under weed free conditions. Nienhuis and Singh (1985) determined that the determinate bush type beans had an asymptotic yield-density relationship whereas indeterminate bush and indeterminate bush beans had a parabolic yield density relationship. In a trial conducted in Alberta, Saindon et al. (1995) found that increasing seeding density from 20-60 plants m^{-2} in two determinate bush beans, increased yields between 10 and 20%. In North Dakota, the yield of a determinate bush navy bean had a linear response to plant population up to the maximum density of 37 plants m^{-2} (Grafton et al. 1988). However, at high densities the yield of determinate bush beans sometimes decreases. Vandenberg et al (1992) found that in two out of three years, determinate bush navy beans had a lower yield when seeded at 60 seeds m^{-2} compared to 45 seeds m^{-2} when grown under irrigation in Saskatchewan. The greater yield at higher densities in determinate bush beans may be due to lower harvest losses. Ablett (1988) determined that a hand harvested cultivar of Determinate bush beans had the highest yield at 60 plants m^{-2} whereas the same cultivar direct harvested had the highest yield at 84 plants m^{-2}.

Camino and Expresso responded differently to increased plant density (Table 8, Figure 7). In general, the yield of Expresso had a more linear response to density, whereas the yield of Camino was less responsive to increased densities. However, at Redvers and Saskatoon in 2000 the yield of Camino responded more linearly to increasing densities. In 1999 the yield of Camino had a more asymptotic relationship at all locations than Expresso, although this was not significant at Melfort (Fig. 7). Nevertheless, in 2000 only Camino at Melfort had a more curvilinear relationship than Expresso. This differential yield density response between cultivars over years may have occurred because of early frost that occurred in 2000. This may have limited the yield of Camino because it matures later than Expresso.

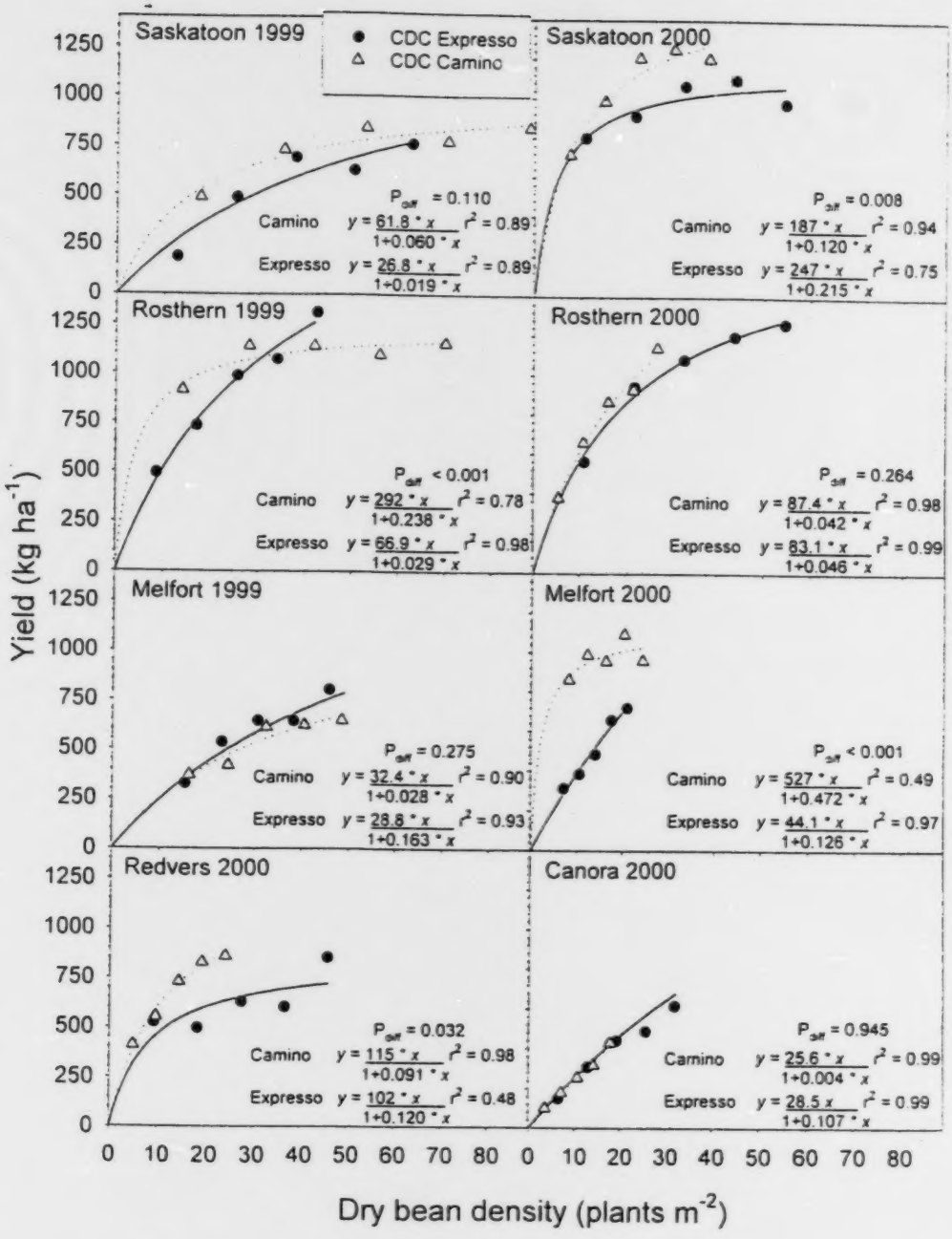

Figure 7. Yield density relationships for CDC Expresso and CDC Camino at experimental locations in 1999 and 2000. Symbols indicate average plant density and lines represent fitted regressions. The probability of the difference between the regressions describing the yield density responses for the cultivars not being different is given by P_{diff}.

3.2.4.2.3 Yield Components

1000 seed weight

Overall seeding rate did not affect 1000 seed weight (Table 8.). Nonetheless, within the individual locations of Rosthern and Saskatoon there were significant linear effects of seeding rate on thousand seed weight for both years. In these environments, as seeding rate increased the thousand seed weight decreased by 6.3% (Rosthern 2000), 4.7 % (Saskatoon 2000), 4.2%, (Rosthern 1999), and 6.1% (Saskatoon 1999). Compared to difference in yields, these differences are small and probably not of agronomic or economic importance. These results are similar to those of Stewart-Williams and Myers (1992) who found that seeding rate had a small effect on 1000 seed weight. A 350% increase in seeding rate reduced 1000 seed weight by only 4%.

There were differences between cultivars in 1000 seed weight with a value of 298.3 for Camino and 183.3 for Expresso (Table 8). These differences reflect the genetic differences in these beans and their specific market classes.

Seeding rate always had a significant effect on seeds produced per m^2. There were significant linear and quadratic effects and the harvested seed density increased with seeding rate (Table 8). There was a significant difference in seed produced per m^2 between cultivars, reflecting the genetic difference in seed weight between Camino and Expresso. The cultivar by seeding rate interaction was also significant although we were unable to determine any pattern in this interaction that was caused by experimental treatments.

3.2.4.2.4 Seeds per plant

Increasing seeding rate lowered seed production per plant with an overall average of 223 and 1000 seeds/plant produced at seeding rates of 100 and 20 seeds m^{-2} respectively (Table 8). A five-fold increase in seeding rate resulted in a two-fold reduction in seeds per plant indicating intraspecific competition. Although cultivar did not have an overall effect on seeds per plant, Expresso tended to have more seeds per plant than within most individual environments. The similarity between seeds produced per plant, coupled with the smaller seeds that Expresso produces may be the reason why Expresso typically required higher densities to reach its maximum yield potential.

Under imposed drought stress conditions in black bean, seeds per pod and pods per plant are much more highly correlated with than seed size (Nielsen and Nelson, 1998).

Increasing the seeding rate resulted in a significant linear effect on seeds per m^2 (Table 8). The lack of variability of 1000 seed weight in bean suggests that yield and bean is limited by seed number and not by seed size.

3.2.4.2.5 Frost Damage

There was no overall effect of seeding rate on percent of frost damaged seeds (Table 8). Nevertheless, at all locations in 2000, Camino had significantly higher levels of frost damaged seeds than Expresso with 5.5 % and 3.4 % frost damaged seeds for Camino and Expresso respectively. This reflects the later maturity of Camino compared to Expresso (data not shown). Although the linear effect of seeding rate on percent frost was not significant for 1999 ($p = 0.0787$), there was a trend where increasing seeding density reduced frost damage. At 100 seeds sown per m^{-2} the percentage frost damaged seeds was 3.7% whereas at 20 seeds sown per m2 it was 5.5%. This suggests that higher seeding rates may reduce but not eliminate frost-damaged seed. This was probably caused by the delayed maturity experienced by plants at low density. In 1999, frost damage did not occur and there was no significant cultivar or seeding density effect on frost damage.

3.2.4.2.6 Optimum Economic Seeding Rate

As both bean cultivars usually had the highest yield at the highest plant populations, it was not possible to determine a optimum biological plant density. However, by using economic parameters it was possible to determine the economic optimum seeding rate. At all locations, Expresso was required to be at higher plant densities than Camino to maximize returns (Figure 8). This reflects the differences between cultivars in the yield-density relationships (Figure 7) and seed cost. Although Camino often had a higher yield potential than Expresso, there were higher seed costs associated with Camino. This was due to the greater 1000 seed weight of Camino (Table 7), which required a greater weight of seed per area to be sown when compared to Expresso. For Camino, the maximum profit would occur in all at a plant population of 25 plants m^{-2} (Figure 8). Maximum profit in Expresso required densities as high as 58 plants m^{-2} at Rosthern in 1999, the maximum density achieved at this location. However, in most environments profits were maximized in the range of densities achieved.

There were differences between locations in net returns (Figure 8) associated with the differences in the yield density relationships (Figure 7). Areas that had low yield potential had low net returns. Often these environments experienced frost, which limited yield production. Nonetheless, areas with low yield potential often had optimum plant densities that were similar to environments with high yield potential. For Camino, only Melfort in 2000 had an optimum plant density that was below 20 plants m^{-2} (Figure 8). The net returns for Expresso varied more between location, with Redvers and Saskatoon in 2000 having optimum plant populations at 21 and 23 plants m^{-2} respectively. The other environments required much higher plant densities to maximize profit (Figure 8).

Economic maximum yield for determinant bush type beans in Saskatchewan is lower than the maximum biological yield. Simply put, a farmer cannot afford to grow the maximum yield. Jettner et al. (1999) found that the optimum plant density for desi chick peas grown in Australia increased with yield potential. In this study yield potential was not closely associated with optimum plant population (Figures 7 and 8).

Other agronomic and environmental factors affect the seeding rate which a farmer would target. Producers who anticipate weed problems may wish to seed beans at higher

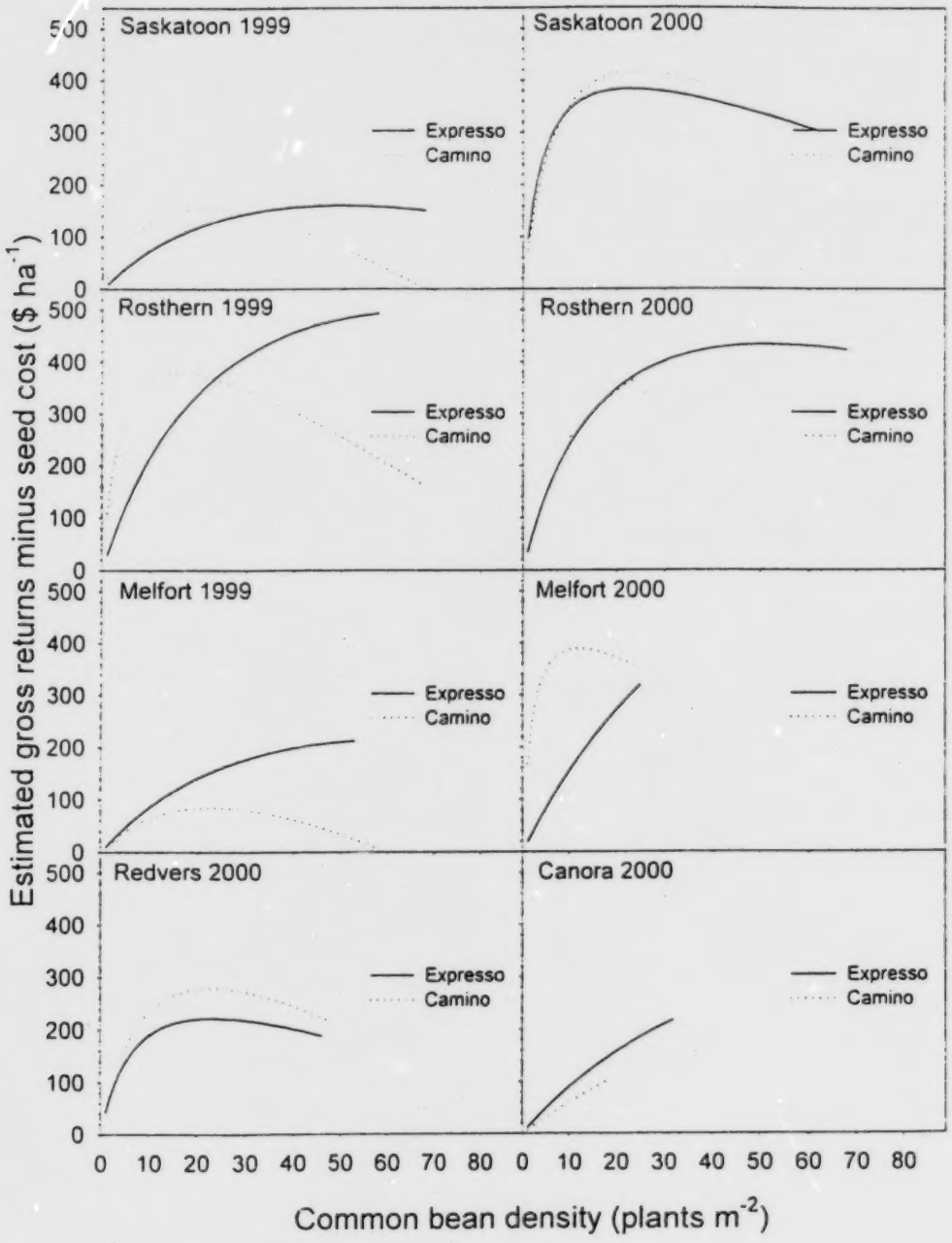

Figure 8. The relationship between net return over seed costs and plant density for CDC Expresso and CDC Camino at experimental locations in 1999 and 2000.

than optimum weed free condition densities. Blackshaw et al. (1999) found that beans seeded in Alberta at 48 plants m^2 suppressed hairy nightshade (*Solanum sarrachoides* Sendtner) biomass production compared to a seeding density of 24 plants m^{-2}. In Ontario under weedy conditions increasing bean density from 25 to 37.5 plants m^{-2} increased yields in one out of two years (Malik et al. 1993).

White mould (*Sclerotinia sclerotiorium* (Lib.) de Bary) was not observed in any of the environments in which this experiment was conducted. Increase in white mould incidence at higher plant populations can be a problem under moist conditions at high plant densities in narrow rows. Upright cultivars have less white mould incidence than viney cultivars and can be grown at high densities without greatly increasing the risk of yield loss due to white mould (Saindon et al. 1995).

The high cost of seed necessitates that common bean be seeded at rates below the biological maximum in order to achieve maximum profits. Growers wishing to maximize profit should target plant populations for CDC Expresso of approximately 50 plants m^{-2}. The target population for CDC Camino should be lower at approximately 25 plants per m^{-2}. At published 1000 seed weights and assuming 70% combined germination and emergence, this is equivalent to a seeding rate of approximately 136 and 115 kg ha-1 for both cultivars for CDC Expresso and CDC Camino respectively

3.3 Conclusions

Tentative conclusions

1) Dry beans can be produced successfully using a no-till system provided crop residue is not excessive.
2) Dry beans should be fertilized with nitrogen fertilizer to maximize yield. A preliminary recommendation of 25-50 kg/ha.
3) Inoculation with rhizobium is beneficial when low rates of fertilizer nitrogen are used (less than 25 kg ha^{-1})
4) Devices to improve harvest efficiency may not always work.
5) The seeding rate for different classes of dry beans maybe different then the current blanket recommendation of 45 seed m^{-2}. A more realistic target seeding rate for CDC Camino is 25 seeds m^{-2}. CDC Expresso should be seeded at 45 seed m^{-2}.

3.4 Information of Benefit to Producers, Processors or Government

All of the above information is of direct benefit to producers and has already been communicated to many directly.

4 Personnel

5 Equipment

No equipment was purchased.

6 Project Developed Materials

No project materials are yet available.

7 Project Photos

8 Acknowledgements

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The Annual Meeting of the SSCA, 2000
The Bean Improvement Co-operative Meetings in Calgary, 2000
The Western Canada Agronomy Workshop in Brandon, 1999
Pulse Tour at the Seager Wheeler Farm, 1999
Shaw, L.D. and S.J. Shirtliffe. 2001. Direct seeding dry bean in Saskatchewan. Soils and Crops 2001. Feb 22-23, 2001, Saskatoon, SK.
July 11 Crop Diagnostics School Kernen Crop Research Farm.
July 13 Pulse Tour Saskatoon. Field Tour.
July 27 Oat Industry Tour Tour. Field Tour.
Aug 3 2000, Bean and Pulse Crop field Day, Rosthern Saskatchewan. Field Tour.
Aug 8 2000, Seager Wheeler Farm Tour Extension Field Day, Rosthern
November 6. Saskatchewan Soil Conservation Association Update. Presentation of Research.2000
November 14 Certified Crop Advisors update. Presentation of bean agronomy research. 2000
November 27. Pulse Crop Information Meeting. Beans the 2000 experience. Rosthern SK. 2000
Dec 11. Bean update meeting Rosthern 2000
Dec 20 Met with Farmers group from Hanley, SK who had questions regarding bean production. 2000
Jan 8 Bean Agronomy Presentation at Pulse Growers Meeting. (Written as well) 2001
Jan 9 Met with Harris crop production club regarding Bean Production 2001
Jan 10 Bean Agronomy Presentation at Crop Production Show. 2001
Jan 23 Bean Presentation Canora Growing Beans from Start to Finish. 2001
Soils and Crops Direct Seeding Seeding Dry Bean in Saskatchewan, Feb 22-23, 2001. Lana Shaw and S.J. Shirtilffe. 329-332.
March 8, Producer meeting, Yorkton. Topic: Narrow Row Bean Agronomy.2001
March 9, Select Seed Grower Edible Bean Production Seminar, Saskatoon, 2001
Saskatchewan. Solid Seeded Bean Agronomy. 2001

April 27, North Central Bean Producers Meeting, Rosthern Saskatchewan 2001.

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